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Measuring the Global Broadband Divide Using Aggregated Crowdsourced Big Data

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Abstract

Growing broadband connectivity is central to development strategies of all countries. Thus measurement of that connectivity and associated broadband divides is an essential foundation for telecommunications and digital policy. Yet traditional broadband measures face challenges of data completeness, accuracy, relevance, timeliness and accessibility.

This paper therefore investigates the potential for measuring broadband connectivity and broadband divides between countries using aggregated crowdsourced big data, based on online survey of connectivity speeds from many millions of users. This data source exposes broadband divides between high-, middle- and low-income countries. While such divides are well known, we demonstrate that this form of big data provides a more complete and accurate picture, alongside other benefits compared to traditional data sources.

We show how this aggregated form of big data offers new insights: into divides between fixed and mobile networks, and download and upload speeds; and we show how it can be used to calculate new broadband indices and to measure readiness for broadband. Acknowledging the limitations of this type of big data to guide broadband divide measurement and related policy decisions, we argue it should be at least a complement to traditional measures given, unlike many big datasets, that it is free to access.

A. Introduction

Access to a broadband Internet connection is no longer a luxury but more of a necessity, part of the basic infrastructure of life that some even argue to be a human right (Weiss et al., 2015). Broadband is seen as fundamental in a modern society to fulfilment of economic, social and political goals (Kelly and Rossotto, 2012; OECD, 2014; GSMA, 2016; Broadband Commission, 2018). As a result, an important foundation for telecommunications – and other – policy will be good quality data on broadband connectivity including the "broadband divide": geographical and other divisions between those who are able to use high-speed broadband and those who are not (Jordán, 2011; Broadband Commission, 2018; ITU, 2018b).

Globally, bodies such as the International Telecommunication Union (ITU) started gathering national-level data on broadband connectivity and divides from the turn of the century, as it became available for individual countries (ITU, 2019). Such data derives largely from administrative records and self-reporting of the telecommunications operators that provide Internet services, often funnelled through national telecommunications regulatory authorities (ITU, 2016; Broadband Commission, 2018). Although widely used, this data has acknowledged shortcomings around issues including completeness, accuracy, accessibility, etc. (Bauer et al., 2010; Helderop et al., 2019).

Given these shortcomings, this paper investigates an alternative approach: use of big data. It specifically asks, "What difference is made by measurement of broadband connectivity and divides based on crowdsourced big data rather than traditional data sources?". Past work (Riddlesden and Singleton, 2014; Hilbert, 2016b) has demonstrated big data's potential in this regard but has not systematically analysed the differential implications of big data; an issue of increasing interest given the growing presence of big data and perception of its value, for example among international agencies (Gabay and Ilcan, 2017).

The next section reviews knowledge about the role and measurement of broadband. The third section presents the methods and dataset adopted in this study, which uses aggregated Internet speed data crowdsourced from millions of users. Results of the analysis using descriptive statistics and aggregated indices are then presented, differentiating results by income level of country: high, middle and low; and in terms of network type (fixed vs. mobile), speed (download vs. upload) and readiness threshold (low vs. high). Finally, the paper discusses the findings in terms of what they tell us about the broadband divide, about the use of this type of big data to measure that divide, and about policy implications of that use.

B. Measuring Broadband and the Broadband Divide

To understand the relevance of measuring broadband using big data, this section reviews existing knowledge to understand the importance of broadband, its traditional measurement, and the potential for crowdsourced data.

At the macro-level, the evidence base on broadband's impact is relatively limited but there is some that shows broadband enabling positive economic growth both at national level (Katz, 2012; Minges, 2016) and also in terms of regional or local development (Prieger, 2013; WWC, 2015; Grubesic and Mack, 2016). This is mirrored at micro-level with evidence of productivity gains for companies that adopt broadband (Katz, 2012; OECD, 2018) and employment / income gains for individuals able to access broadband (Whitacre et al., 2014; Akerman et al., 2015). Though much less studied there is also evidence of access to broadband being positively associated with facets of political and social development (Fuentes-Bautista, 2014; Campante et al., 2017; Broadband Commission, 2018).

While the overall evidence base is mixed – including examples of broadband correlated with null or even negative development impacts (LaRose et al., 2011; Belo et al., 2013; Ford, 2018) – the balance leans towards positive impacts, and that is certainly the perception driving both policy and investment. As noted in the Introduction, a central concern has therefore been the "broadband divide": a lack of access to development benefits for those unable to make effective use of broadband. This has multiple dimensions including within-country gaps between ethnic groups (Prieger and Hu, 2008), between urban and rural areas (Prieger, 2013), and between men and women (Fowlie and Biggs, 2015). There has also been an issue of between-country gaps, especially a broadband divide between the higher-income countries of the global North and the lower-income countries of the global South (Weiss et al., 2016; A4AI, 2018; Broadband Commission, 2019). It is this latter – the between-country broadband divide – which will be our focus here, though our findings will have relevance for other divides.

Over time, conceptualisation of the broadband divide has updated and expanded in various ways. Four aspects will be discussed here: infrastructure, value chain, speed, and quality of service.

Broadband was initially delivered via fixed-line services; hence measures of the broadband divide focused on fixed broadband. More recently, broadband has increasingly been delivered via mobile networks; especially in the global South where there have been hopes that countries might "leapfrog" over their limited fixed-line infrastructure (Weiss et al., 2015; A4AI, 2018; UNCTAD, 2018). Any understanding of broadband thus needs to cover both types of network.

In relation to the value chain, the original concern was about availability: did users have access to broadband and, if so, how many could access it. The divide was thus thought of in terms of measures such as existence of broadband services within a country, geographical coverage, number of subscribers (Vicente and Gil-de-Bernabe, 2010). More recently, concern has expanded from availability to adoption and use (Heeks, 2018). There has thus been interest in the cost of broadband, given the link between affordability and adoption;

and in the skills available to make effective use of broadband connectivity. The focus on use also means interest in broadband speed and other aspects of service quality (Hilbert, 2016b).

Growth in videoconferencing and video sharing, cloud applications, machine-to-machine communications and other data-intensive applications – and increasingly concurrent use of such applications – all require bandwidths well beyond the original definition of broadband (Kelly and Rossotto, 2012; OECD, 2014; Broadband Commission, 2018; Ericsson, 2018). That original definition labelled download speeds above 256 kbps as "broadband" but more recent updates have seen, for example, the Broadband Commission (2019) define broadband download speed as 3Mbps and "good quality" broadband download speed as 10Mbps.

Finally, the original usage focus looked solely at download speeds. More recently, there has been an expansion in focus to also include upload speeds in measurements of quality of service, reflecting a broad shift in user models; from users simply being consumers of downloaded data to also being producers of high data volumes that must be uploaded (Cisco, 2017a; Cisco, 2017b; Ofcom, 2019b; Broadband Commission, 2019b). Alongside has been a growing concern that long latency times for transmission to servers can undermine quality of service for some consumers; particularly in the global South (A4AI, 2018; Liu et al., 2018).

Traditional openly-accessible worldwide measures of broadband have been fixed and mobile broadband subscriptions, and population covered by mobile broadband services (ITU, 2016; Broadband Commission, 2018; ITU, 2019). Non-openly-accessible measures in the paid-for ITU database include broadband technology type, service activation time, cost, traffic and subscriptions categorised by fixed-network speed type (ITU, 2019). Even when reported by other sources (e.g. World Bank, 2020), these data invariably derive from the International Telecommunication Union. The ITU in turn has derived this data from two sources (ITU, 2011; ITU, 2014; Ofcom, 2019a). First, from national telecommunications regulators who compile data from the telecommunications operators that provide broadband services and report about these. Second, from some national statistical offices who sometimes use surveys to capture data on broadband speed and cost from individual households.

There are a number of recognised shortcomings of this approach to measurement of broadband (UN, 2005; Bauer et al., 2010; Hilbert, 2016b; Helderop et al., 2019), which we will summarise using the CARTA set of data qualities: completeness, accuracy, relevance, timeliness and accessibility (adapted from Heeks, 2018). Traditional broadband data is incomplete. Only one of the quality of service indicators described above is even partly covered: category of download speed on the fixed network. The data is not available for all countries as some regulators and even operators have problems compiling or reporting; some operators also refuse to release data on grounds of commercial confidentiality. Because the data relies largely on self-reports from telecom operators without triangulation, then its accuracy is uncertain. There has also been uncertainty and potential for inaccuracy due to differential interpretation of indicators by those reporting. Relevance is questionable; in terms of speed, for example, data relates to advertised or theoretical speeds which may well not correspond to the real speeds experienced by users. But it is those latter speeds that determine development impact. Timeliness of data is lacking because of the time it takes for operators to gather data, then typically pass it on to national regulators, then to the ITU. There may then be some iterations of checking data so that confirmed (i.e. non-estimated) data is always about one year old and sometimes more. Finally, there are accessibility challenges given the c.US$300 cost of the database.

Across a growing number of domains, big data is increasingly seen as advantageous compared to traditional data sources (Mayer-Schonberger and Cukier, 2013; Hilbert, 2016a) and there is interest among agencies such as the ITU to investigate its value for Internet-related measurement (Vall, 2017). Big data has been used already for measurement of broadband divides, in the form of crowdsourced broadband speed check data, as used in this paper. Such use appears limited, perhaps because of the high cost or inaccessibility of broadband big data for most researchers, but it has been seen to measure broadband connectivity within countries (Riddlesden and Singleton, 2014) or within subsets of countries (Rojas and Poveda, 2017; FCC, 2018). It has also been used in conjuction with traditional ITU data for global between-country measurement, though focusing on bandwidth rather than speed and complemented by other data sources (Hilbert, 2016b; see also Abeliansky and Hilbert, 2017). All of these examples demonstrate the potential value of big data in measuring broadband. But the object of their research has been tracking broadband progress and divides rather than, as here, the implications of replacing traditional with big data.

C. Research Dataset and Methods

To conduct this study we identified five potential sources of big data (see Table 1), each with different data points and characteristics, which could be used to measure broadband. For comparison, the traditional ITU dataset is also included.

Table 1 Big data sources available to measure broadband services

Source	**Fixed**			**Mobile**			**Frequency**	**Source**	**Open raw data**
	Download	**Upload**	**Latency**	**Download**	**Upload**	**Latency**			
Akamai	✓						Quarterly*	Sensor	No
M-Lab	✓	✓	✓	✓	✓	✓	Daily	Crowd[+]	Yes
Netflix	✓						Monthly	Crowd[+]	No
Ookla	✓	✓		✓	✓		Monthly	Crowd[+]	No
Ookla-Cisco	✓	✓	✓	✓	✓	✓	Yearly*	Crowd[+]	No
ITU	✓			✓[#]			Yearly	Admin	No

* Frequency of public release of these data is not guaranteed.
+ Crowdsourced data are generated by a request initiated by a user but the measurement is produced by a machine.
[#] Only in paid-for database and for a more limited sub-set of countries.
Source: Akamai (2017), Cisco (2017b), M-Lab (2020), Netflix (2020), Ookla (2020)

Table 1 shows that only M-Lab and Ookla-Cisco have download, upload, and latency data for both fixed and mobile networks. While M-Lab's raw data is frequent and accessible, there is at present little data for the majority of countries, thus making it unsuitable for our purposes. This left the crowdsourced Ookla-Cisco dataset as the best available option, with Ookla's data recognised by other researchers as a reliable source (Bauer et al., 2010; EIU, 2018).

The most-recent complete dataset at the time of writing was that generated using 360 million records created during 2017 by Internet users whilst verifying the speed of their Internet connections through a web service or a mobile application.[1] Then these data were acquired by Cisco, processed and released as an aggregated dataset at the country level on the Cisco Global Cloud Index webpage (Cisco, 2017a; Cisco, 2017b). We then extracted the data from the Cisco webpage collecting, in total, data for both fixed and mobile networks of 112 countries covering both mean and median values for download and upload speed and latency.[2] These countries were then categorised based on the World Bank (2019) and OECD (2017) country classifications for 2017 to consist of 45 high-income countries, 59 middle-income countries, and 8 low-income countries[3].

This dataset thus has two important limitations. First, Ookla does not provide direct, open access to the source big data. We therefore have to work only on the aggregation provided by Cisco which constrains the nature of statistical analysis that can be undertaken. Second, the low-income country part of the dataset is small and likely – given the more limited number of users in those countries – to be itself based on a relatively limited number of speed tests. In particular, and as noted below, the eight data points for fixed upload speed are unexpectedly high and can thus lead to only uncertain conclusions.

The research strategy is based on a quantitative approach with two main stages: descriptive analyses and measurement through indices with the latter being explained below. The first stage comprised four sub-stages: i) exploratory analyses including investigation of mean vs. median speeds; ii) descriptive analyses using medians by country income group; iii) measurement of the divide between mobile vs. fixed networks; and iv) measurement of asymmetries between download vs. upload speeds. In addition to the exploratory and descriptive analyses, Wilcoxon signed-rank tests and Kruskal-Wallis tests were also used, as explained further below.[4]

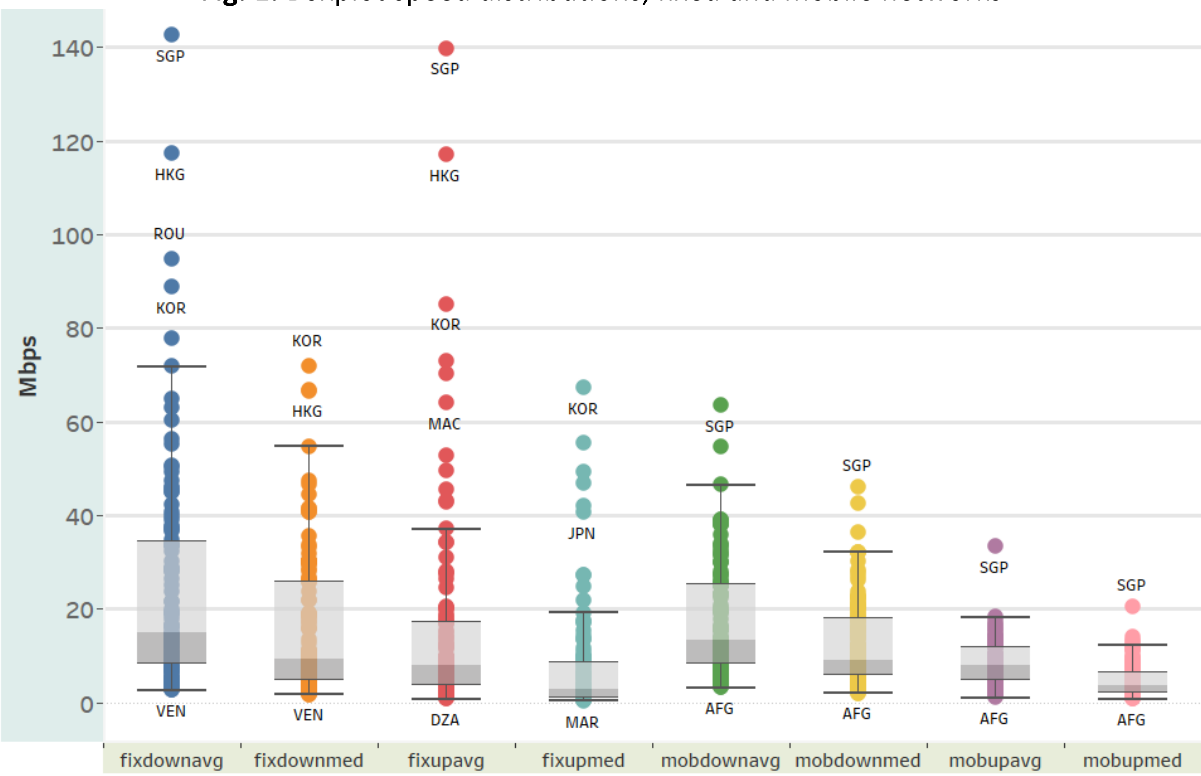
[1] Ookla provides free speed tests to Internet users available in 17 languages, and stores and aggregates the results of these tests in order to produce a monthly index: the "Speedtest Global Index" with information on the average speed of broadband connections at the country level for fixed and mobile networks (Ookla, 2020).
[2] Data for a further 23 countries was excluded because it covered only the fixed network.
[3] Using the OECD (2017) ODA DAC list, "least-developed countries" and "other low-income countries" were categorised as "low-income"; "lower middle-income countries and territories" and "upper-middle income countries and territories" were categorised as "middle-income". Countries not on the DAC list were categorised as either "high-income" or "middle-income" based on World Bank's (2019) categorisation of GNI per capita in 2017.
[4] We also undertook regression analysis on one of the indices developed but, for reasons of brevity, that is not reported here.

D. Results

D.1. Descriptive Statistics

To explore the download and upload speeds for fixed and mobile networks, the values of country means and medians are presented using boxplots (see Figure 1; data presented in Appendix A); a technique to present the dispersion of data in a simple fashion (Cramer and Howitt, 2004; Stockemer, 2019).

Fig. 1. Boxplot speed distributions, fixed and mobile networks



Note: Fixed networks are identified with the prefix “fix” and mobile networks with “mob”; download speeds are contracted as “down” and upload speeds as “up”; means are given the suffix “avg”, and medians “med”.
The box contains 50 percent of all cases, with the upper and lower sides of the box (quartile 1 [Q1] and quartile 3 [Q3]) showing the boundary of the remaining 25% of the cases, respectively; the middle line inside the box represents the median value (quartile 2 [Q2]). The whiskers show the minimum and maximum value excluding outliers, and they are derived from the interquartile range (IQR=Q3-Q1): lower whisker = Q1 - 1.5 * IQR; upper whisker = Q3 + 1.5 * IQR. The data plotted as a circle above or below the whiskers represents the outliers.
Source: Authors using Ookla-Cisco dataset, 2017

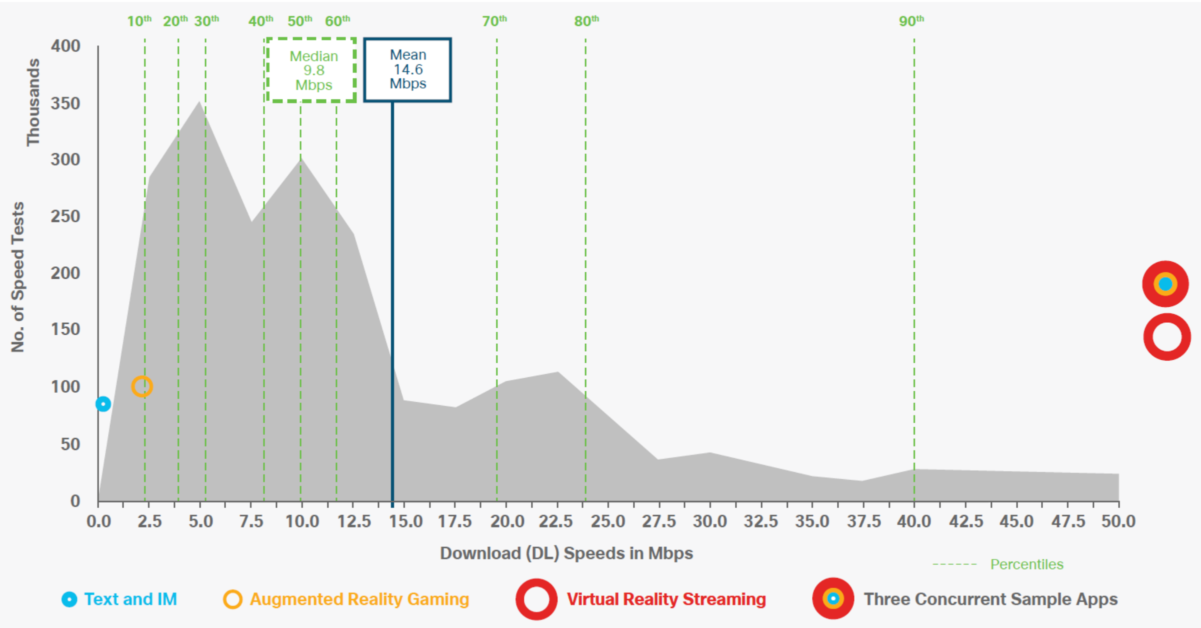
The data suggest two things that could not be derived from traditional data sources. First, that the higher speeds are found on the fixed networks (e.g. comparing the position of the higher whisker for comparable measures between fixed and mobile networks) but that other comparisons between fixed and mobile networks are harder to make. For instance, there does not appear to be any great difference between the median values for fixed and mobile networks, perhaps reflecting the speed gains seen on mobile networks over the course of the century. It will therefore be useful to investigate fixed–mobile differences further below.

Second, and despite the growing requirements for upload parity, upload speeds appear to be on average well below download speeds. It will therefore also be useful to investigate download–upload differences further below. Download speeds themselves are not that exemplary, with the majority of countries' highest speed, on the fixed network, below 15Mbps using means and below 10Mbps – the Broadband Commission's definition of good quality broadband – using medians.

This differential of means and medians[5] exposes a third finding that traditional data sources could not derive: that median speeds are always well below mean speeds. This was statistically validated through comparison of mean and median download and upload speeds for both fixed and mobile networks using a Wilcoxon signed-rank test.[6] In all cases, H_0 (mean = median) was rejected in favour H_a (mean ≠ median). We can therefore say that mean speeds are faster and statistically different to median speeds, indicating a positive skew of data.

As a measure of central tendency the median is more resistant than the mean to extreme values and skews (Stockemer, 2019). As an illustration, Figure 2 shows the mean, median and distribution of fixed network download speeds for Mexico. The distribution is significantly positively skewed i.e. towards lower recorded speeds. Only a little over one third of the population experiences speeds above the mean which is raised to 150% of the value of the median due to a small proportion of high-speed outliers. As in theory, so in practice, the median is a better measure of average than the mean.

Fig. 2. Distribution of download speeds for fixed network, Mexico



Source: Cisco (2017b)

[5] The mean is the arithmetic average while the median is the midpoint of a range of values (leaving 50 per cent of values above and 50 per cent below).

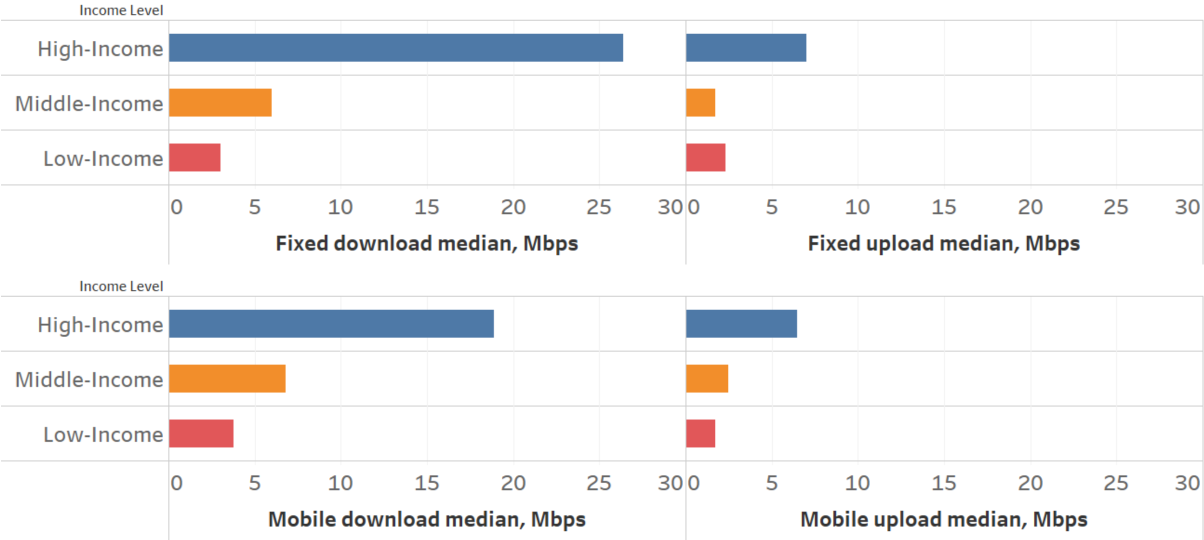
[6] The Wilcoxon signed-rank test is a non-parametric test that can be used when the difference between two measurements is not normally distributed, assuming an ordinal difference in the variables. It was used here to identify the differences between two sets of observations (speeds at the country level) that are not independent, to find if there is a statistically significant difference or not; this test defines a null hypothesis (H_o) and an alternative hypothesis (H_a) (Suchmacher and Geller, 2012; Scheff, 2016; UCLA, n.d.). In our case H_o assumes that the mean is equal to the median; H_a assumes the mean is different from the median.

Research including broadband speeds quite often uses mean values (Kongaut and Bohlin, 2014; Nardotto et al., 2015; Gijon and Whalley, 2018). But the widespread presence of skew in distribution of broadband speeds leads us to conclude that it is median values which should be used instead as they are more representative of the real speeds observed by the majority of users in a country.

D.2. Broadband Speed Divide

A key use of global broadband data has been to identify inter-country differences, and we now move to this using – for the reasons just given – median speeds as most-representative of real speeds. This country data itself is also positively skewed so we summarise in terms of medians, with figures for the three country types presented in Figure 3, broken down into fixed and mobile (upper and lower panels respectively) and download and upload speed (left and right panels).

Fig. 3. Median speeds on fixed and mobile networks by income-level group



Source: Authors using Ookla-Cisco dataset, 2017

The data shows a clear hierarchy and divide: broadband service is much better in high-income countries than others, and in general better in middle-income than low-income countries. The divide is sharpest in relation to download speeds on the fixed network: high-income country median speeds are more than four times faster than those in middle-income countries, and more than eight times faster than those of low-income countries. Differentials are not quite so large but still sizeable for download speeds on mobile networks. For upload speeds, there is a similar differential between high-income and less-wealthy countries but less difference between the middle- and low-income countries. Differences were statistically validated through application of Kruskal-Wallis tests.[7] In all cases except that of middle- vs. low-income countries for fixed upload, H_o (aggregated speed is equal across all income level groups) was rejected in favour of H_a (aggregated

[7] The Kruskal-Wallis test can be used to identify disparities within a dependent variable given some different levels defined by an independent variable. This test allowed us to identify the statistical significance of disparities within a dependent variable (speed), given some levels defined by an independent variable (country income-level group) (Scheff, 2016). In this case H_o assumes that the aggregated speed is equal across all country income levels; H_a assumes the aggregated speed is not equal across all country income levels.

speed is not equal across all income level groups). The difference in broadband speed between income levels of countries is therefore statistically significant.

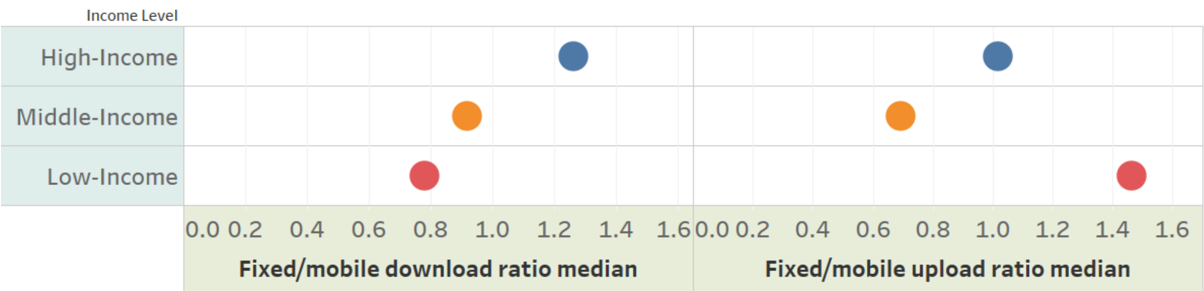
The broadband divide between countries exposed by this aggregated big dataset is not particularly surprising. Similar hierarchies and divides emerge through analysis of traditional data sources on broadband speed categories, broadband coverage and subscription levels (ITU, 2018b). All that the crowdsourced data adds here is a somewhat fuller picture given the addition of mobile network and upload data.

There is a further potential value, at least for some countries. The speed data compiled by ITU counts subscriptions within three fixed network download speed segments: 256Kbps–2Mbps; 2Mbps–10Mbps; and 10Mbps or more (ITU, 2018b)[8]. Yet average high-income country speeds on the fixed network, as shown in Figure 3, are well above 10Mbps. This reflects the fact that roughly 90 percent of high-income countries fall into the ITU's 10Mbps+ category (ITU, 2018a), so it is no longer a good within-category differentiator. By contrast, this big data source can readily be used to differentiate: say if one wished to split countries into <10MBps, 10–50 Mbps and >50Mbps categories[9].

D.3. Fixed–Mobile Speed Divide

Particularly given the aspirations for mobile networks in lower-income countries noted earlier, it is important to measure the speed experienced on these networks relative to fixed networks to see if there is any fixed–mobile divide. Such investigation is only possible with the crowdsourced big data not with traditional data. Some sense of this was present in Figures 1 and 3 but here we use a more direct comparison. Figure 4 shows the result of calculating the ratio of median speeds between fixed and mobile networks for each individual country and then taking the median of these for different country types; distinguishing download and upload[10]. Ratios are above one where fixed network speed is faster on the aggregate; below one where mobile network speed is faster.

Fig. 4. Ratio fixed / mobile, download and upload speeds by income-level group



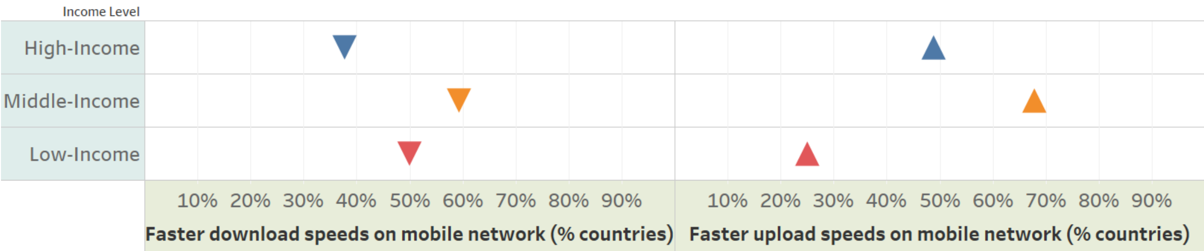
Source: Authors using Ookla-Cisco dataset, 2017

[8] These are advertised not actual speeds.
[9] Additional segments for higher speeds have been already defined by the ITU (10–100Mbps; 100Mbps–1Gbps; >1Gbps) (ITU, 2011); however, when the 2018 indicators were released, data were only available for the first three segments (ITU, 2018a).
[10] Median values are again used to calculate group aggregates rather than means because the country dataset is positively skewed, and so use of the mean would give a less-representative picture.

Overall figures across all countries show no great fixed–mobile network divide: download speeds experienced on fixed networks are just 2% faster than the mobile networks; upload speeds experienced on mobile networks are 23% faster than those on fixed networks. As might be predicted given the different roles of fixed and mobile networks in the global North and South, there are differences by income level. Speeds experienced on fixed networks are faster in high-income countries (only just for upload speeds). Speeds experienced on mobile networks are greater overall in lower-income countries (excepting the anomaly of low-income country fixed upload speeds noted above).

To provide a further perspective on the disparities between fixed and mobile networks, Figure 5 identifies the proportion of countries in each category that record faster speeds on mobile networks; noting again that this information is only available via big data. Consistent with the data shown in Figure 4, the majority of middle-income countries are experiencing faster download and upload speeds on the mobile network (59% and 68% respectively). This all represents valuable information e.g. for policy makers considering the relative speed contributions and value of fixed and mobile infrastructure.

Fig. 5. Faster experienced speeds on mobile compared to fixed networks, download and upload by income-level group

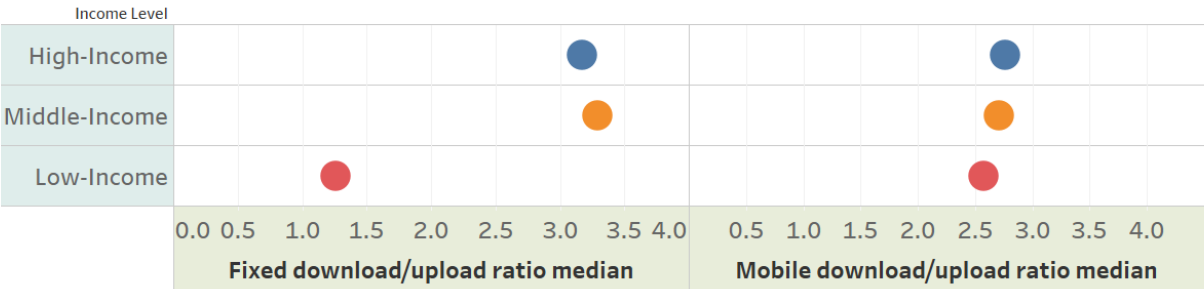


Source: Authors using Ookla-Cisco dataset, 2017

D.4. Download–Upload Speed Asymmetries

As noted above, the shift from users as digital consumers to also being digital producers means that an ideal network would provide upload speeds similar to download speeds. With traditional datasets it has not been possible to investigate this but the Ookla-Cisco dataset allows us to calculate the (a)symmetry of telecommunication networks. Figure 6 shows the result of calculating the ratio of median download:median upload speeds for each individual country and then taking the median of these for different country types; distinguishing fixed and mobile networks.

Fig. 6. Ratio download / upload speed, fixed and mobile network by income-level group



Source: Authors using Ookla-Cisco dataset, 2017

Again setting a question mark over the low-income country fixed upload figures, we can see that asymmetries across income levels and across networks are fairly consistent. Despite the much greater investments in broadband infrastructure in high-income countries, and despite the much greater role of mobile networks in lower-income countries, neither effect can really be seen in the data: download speeds are around three times faster than upload speeds in all cases. Comparing the two network types, then overall ratios / asymmetries are only around one-sixth higher on fixed compared to mobile networks, suggesting relatively limited benefits on this particular measure for those focused on mobile network investment. Finally, the figures suggest relatively limited impact at the time of sampling of superfast fibre fixed networks and of 5G mobile networks, both of which allow symmetric download/upload, unlike earlier generations of the technologies[11]. With growth in digital producer roles including data-intensive production such as video upload as part of digital economy strategies, policy makers will be increasingly needing these types of insights in order to determine investment and regulatory priorities.

D.5. Broadband Indices

Notwithstanding its aggregation, this crowdsourced big dataset has allowed us to separately explore multiple dimensions of the broadband speed divide; something not possible with traditional broadband data. But we can also use this dataset to do the opposite: create a broadband index figure for each country. Indices have been popular in measuring the digital divide as they aggregate multiple dimensions into a single figure and readily allow comparisons between countries and across time (OECD, 2008; Bruno et al., 2010; Hanafizadeh et al., 2013). In this case, we calculate the broadband index giving equal (i.e. one-third) weight to median download speed, median upload speed, and latency[12]. Standardisation is required in order to enable the three elements to be combined (OECD, 2008); normalising the distributions, moderating the effect of outliers and adjusting values to a 0–1 scale based on the following rescaling formula:

$$resc = \frac{x - min}{max - min}$$

Each of the three elements is rescaled to a maximum value of 1/3. Within the upload and download segments a value of 1/3 is given when the country has the highest speed, and a fraction of the value if this is lower; latencies work in the opposite direction as the ideal is to have lower values closer to zero. Given the differential roles of, and policies towards, fixed and mobile networks in different countries, we decided to create separate indices for each type: *ifix* for the fixed network, *imob* for the mobile network according to the following formulae:

- *ifix* = ((1/3 * download $speed_{fixresc}$) + (1/3 * upload $speed_{fixresc}$) + (1/3 (1-$latency_{fixresc}$)))

[11] At an individual country level, impacts can be seen. For example, the best-performing country on the mobile network – Singapore – had a mobile download/upload ratio of 2.3 (three-quarters the high-income country average), and the best-performing country on the fixed network – South Korea – had a fixed download/upload ratio of 1.1 (one-third the high-income country average).

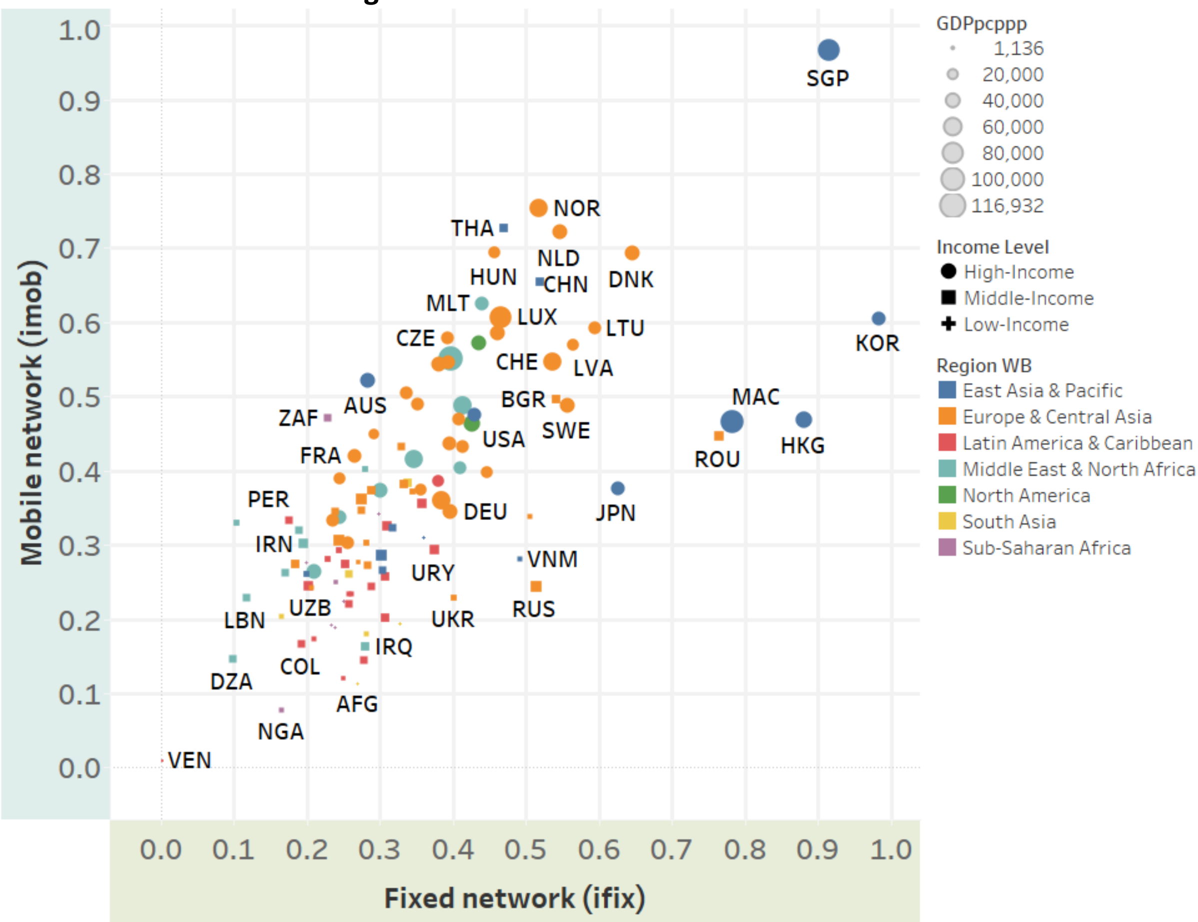
[12] Equal weight has usually been given to each of these three elements by researchers using these types of data and for instance in the estimation of the EIU (2018) index; however Vicente and Gil-de-Bernabé (2010) suggest the use of different weights which could be valuable to lower the importance of latencies.

- $imob = ((1/3 * \text{download speed}_{mobresc}) + (1/3 * \text{upload speed}_{mobresc}) + (1/3\ (1-\text{latency}_{mobresc})))$

As a result the *ifix* and *imob* indices for each country can take values between 0 and 1: values closer to 1 reflect relatively fast download and upload speeds, and relatively low latencies compared to the country with the best performance in each dimension (see Appendix B for data). Thus the indices can be useful policy tools, helping any individual country understand where it stands in relation to others; for example, creating a "league table" of broadband performance either separately for fixed and mobile, or combining the two into a single measure. These can be important for digital development given the role that indices and league tables play in shaping and even stimulating policy action (Kauffman and Kumar, 2005; Gerpott and Ahmadi, 2015).

We can also gain insights through visualisation of the indices: Figure 7 is a country-level scatterplot of the *ifix* index (x-axis) and *imob* index (y-axis). The size of each point represents the country GDP per capita in US$ purchasing power parity; the shape indicates the country income-level group; and the colour shows the region.

Fig. 7. Fixed and mobile network indices



Source: Authors using Ookla-Cisco dataset, 2017

The first thing to note is the reasonable degree of clustering around the line of best fit: there is a fair degree of correlation between performance on the two indices. Some countries are offset below and to the right of the line: in these the performance of the fixed network relative to other countries is greater than the relative performance of the mobile network. For those countries towards the right side of the graph, this likely occurs due to their significant investments in high-speed fibre-optic broadband; something easier for the city-states/territories represented[13]. Most countries, though, lie above and to the left of the x=y diagonal, reflecting the differing general distribution of the two indices: the *ifix* indicator is more positively-skewed with countries concentrated more towards the lower part of the distribution than is the case for the *imob* indicator[14]. This may again reflect the influence on the indicator of the outlier countries with some very high-performing fixed broadband infrastructures.

Looking at the upper-right of the graph, we find countries with the best-performing broadband overall. Singapore stands out, leading in the performance of both its fixed and mobile networks. With a few exceptions – e.g. Thailand and China – almost all countries in this high-performing part of the graph are high-income countries, as one would expect from earlier findings. Looking at the lower-left of the graph, we find countries with the worst-performing broadband infrastructure. Venezuela stands out, with the lowest scores for both indices. Virtually all countries in the low-performing part of the graph are lower-income countries, thus illustrating the global broadband divide relating to income[15].

D.5.1. Fixed network broadband index

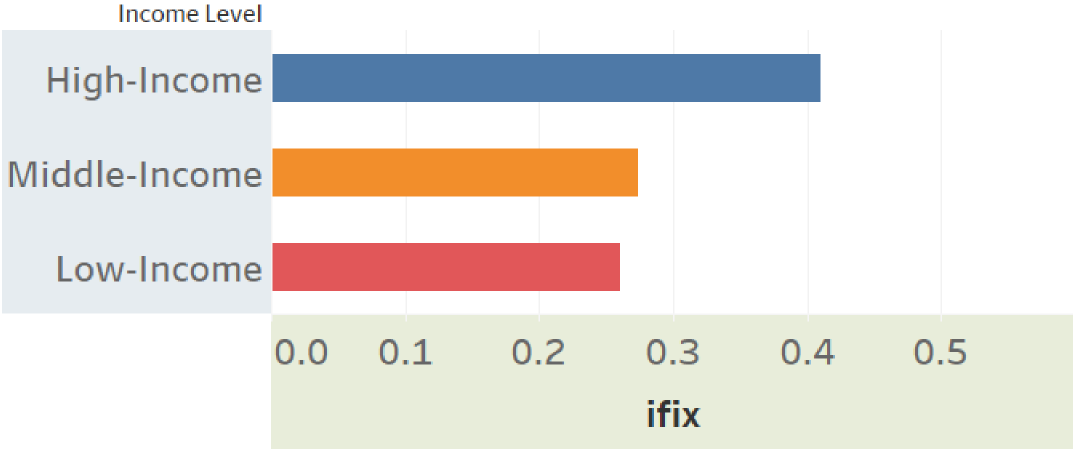
To confirm these disparities we present the results of the calculation of the *ifix* indicator aggregated for all countries by income-level group in Figure 8. The *ifix* indicator clearly shows the divide between high-income countries and the other two groups. The scores for the two lower-income groups are around one-third lower when compared to those obtained by high-income countries. There is no difference between the scores given to middle- and low-income countries on this network: the low-income sample has fixed network performance similar to that of the average middle-income country and may thus not be representative of low-income countries overall. A Kruskal-Wallis test confirms the divide between high-income countries and the rest of the world. The *ifix* index confirms that a global broadband speed divide exists and that high-income country users benefit from better service on fixed networks.

[13] For more on why Romania is in this group, see Rogers (2015).

[14] Note, the independent calculation of the two indices means the graph is not showing the performance of mobile and fixed networks relative to one another in a country. The upward offset therefore does not mean mobile networks in most countries are performing better than fixed networks in those countries.

[15] The lowest-scoring countries are middle- not low-income countries, likely reflecting the issues with low-income country data noted earlier.

Fig. 8. Fixed network broadband index by income-level group

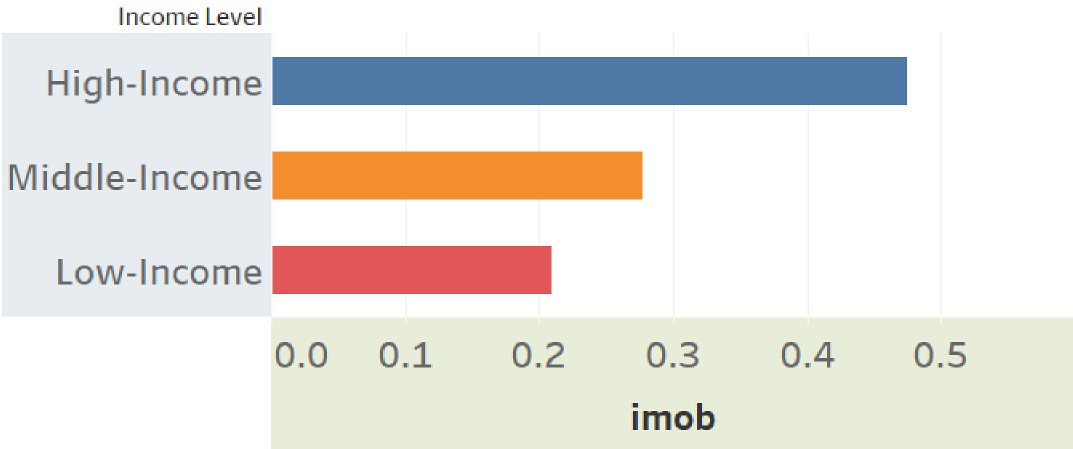


Source: Authors using Ookla-Cisco dataset, 2017

D.5.2. Mobile network broadband index

Similar calculations are performed on the mobile network; Figure 9 presents the results for *imob*[16]. It shows a clear divide across country income levels. Once more, high-income countries get the highest scores, followed by middle- and then low-income countries. The aggregated scores of middle-income countries are around one-third lower than those of high-income countries; low-income countries have scores that are less than half of the high-income countries and around one-third lower than middle-income countries. These differences are statistically significant between high-income countries and others when performing the Kruskal-Wallis test, and confirm an income-related divide.

Fig. 9. Mobile network broadband index



Source: Authors using Ookla-Cisco dataset, 2017

Overall, via the *ifix* and *imob* indices we are able to explore multiple dimensions of the speed divide as a joint score for countries in our dataset. The results confirm presence of a global broadband speed divide. Fixed and mobile networks in high-income countries have better performance when compared to those in middle- and low-income countries, which

[16] As noted above, while we can compare the values of both indices, a score of – for example – 0.5 on *imob* does not mean performance on the mobile network equal to a 0.5 on the *ifix* score due to the independent calculation and re-scaling of each index.

are least able to benefit from the use of data-intensive services and applications. None of the measurements in this section could be performed with traditional data.

D.5.3. Broadband readiness calculations

We can also use indices to understand the broadband readiness of nations using two thresholds estimated by Cisco (2017b) (see Table 2). The low threshold is based on performance requirements for a country to be on the “cusp” of using data-intensive services; the high threshold reflects requirements for full use of data-intensive services: concurrent use of multiple services including basic (e.g. text/instant messaging), intermediate (augmented reality) and advanced (virtual reality streaming).

Table 2 Low and high thresholds, data-intensive services and applications

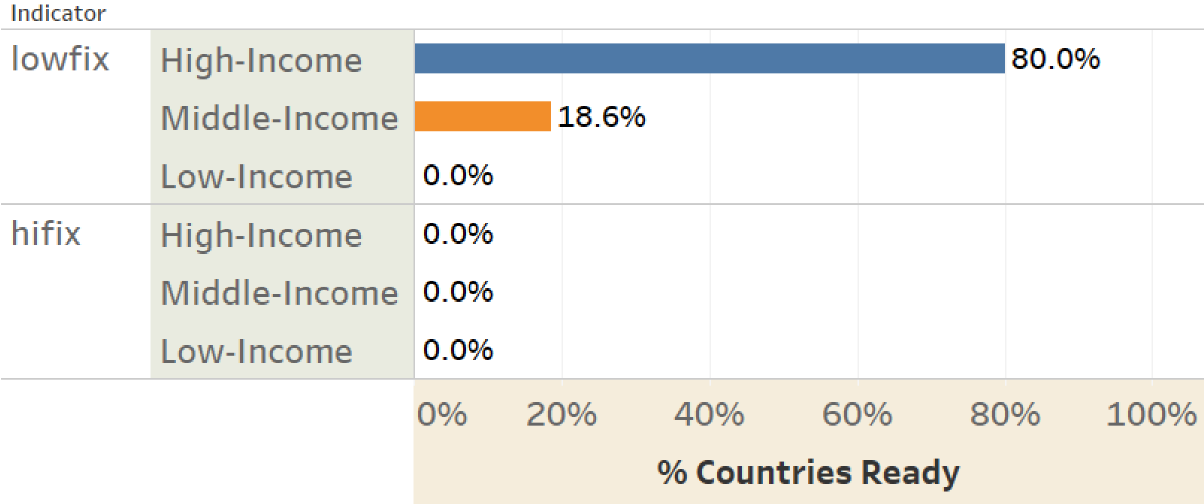
Threshold	Download (Mbps)	Upload (Mbps)	Latency (ms)
Low	More than 9.1	More than 2.1	Less than 56
High	More than 85	More than 85	Less than 20

Source: (Cisco, 2017a; 2017b)

Indices were created for the low and the high thresholds, for both fixed and mobile networks: *lowfix*, *lowmob*, *hifix* and *himob*. As above, each of the three components is equally weighted with upload/download getting a value of 1/3 when median speed is equal to or greater than the threshold value and a fraction of this value if lower; and latency getting a value of 1/3 when median latency was equal to or lower than the threshold value and a fraction of this if higher. In sum indices can take values between 0 and 1, with a value of 1 meaning the country is ready based on the threshold criteria.

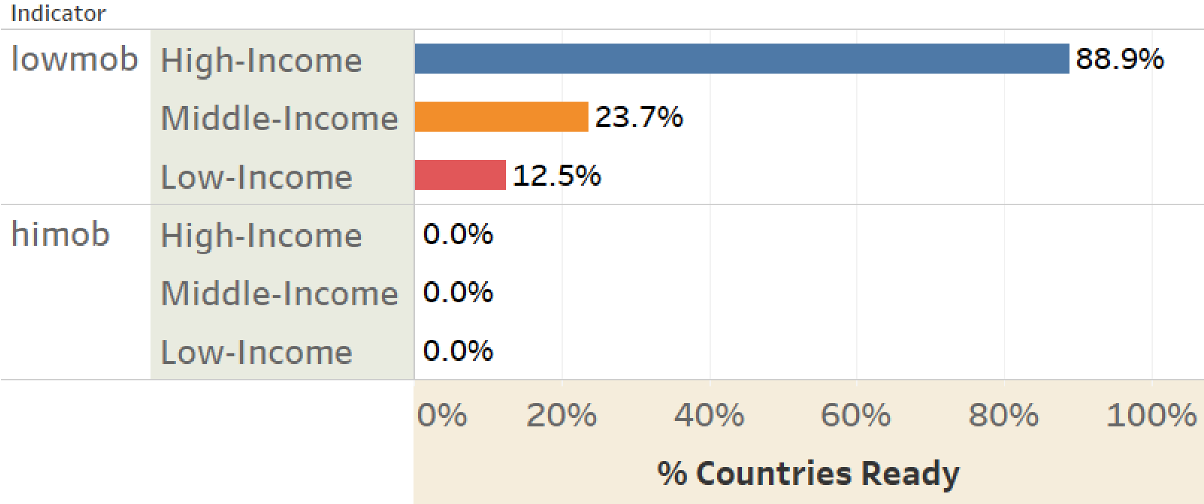
For both fixed (Figure 10) and mobile (Figure 11) networks, patterns are the same. The great majority of high-income countries are ready at the low threshold but this was true of only a small minority of middle-income countries, and only one of the low-income countries, for its mobile network alone. This readiness measure therefore reiterates the global pattern of broadband divide by income. No countries are yet deemed ready for full use of data-intensive services as per the high threshold. We believe these threshold measures will be of value to policy makers in understanding readiness of their countries e.g. for particular types of participation in the digital economy and society. Again, these measures are not available with traditional broadband data sources.

Fig. 10. Countries ready on the fixed network, low and high thresholds (%)



Source: Authors using Ookla-Cisco dataset, 2017

Fig. 11. Countries ready on the mobile network, low and high thresholds (%)



Source: Authors using Ookla-Cisco dataset, 2017

E. Discussion

The discussion in this section focuses around two topics that address our main question: "What difference is made by measurement of broadband connectivity and divides based on crowdsourced big data rather than traditional data sources?". First, the insights into dimensions of the broadband speed divide that this aggregated big dataset has provided, and then a summary of the comparative opportunities and limitations of using this form of crowdsourced data.

E.1. Insights into Broadband Speed Divides

What new insights has this big data-based analysis provided?

The first insight was methodological; identifying a differential between mean and median broadband speeds within individual countries. Analysis was limited by lack of access to the raw big data and presentation of distribution profiles for only six countries. However, from the available data and statistical testing, it was possible to demonstrate that medians are a better reflection than means of observed broadband speeds in a country, due to positive skews / outliers in speeds. As noted above, to date, most studies use mean speeds (theoretical or observed) for research analysis and policy recommendations. Results here support the argument that medians will be a better way to understand broadband and broadband divides in a country, and a better basis for making policy decisions.

Using median speeds aggregated into country types by income, we were able to identify a global broadband speed divide. There was a fairly consistent correlation of speed and income; particularly reflected in much faster speeds experienced by high-income countries compared to others. On average, middle- and low-income countries have not yet achieved "good quality" broadband; thus restricting their ability to build and participate in digital economies and societies. While such a finding is not new, we argue that the basis for our big data-based analysis – bar the concerns about low-income country fixed upload data – may be an improvement on more traditional approaches. This derives from the greater accuracy and relevance of the data including use of medians, use of individual speeds rather than speed categories, and use of real not theoretical speeds.

Use of the crowdsourced dataset permitted deeper investigation of specific dimensions of the broadband divide; something not possible with traditional broadband data sources. The first of these is a fixed–mobile divide which, while not great, was differentiated by country income group. In aggregate, speeds experienced on fixed networks were faster than those on mobile networks in high-income countries; but the reverse was true in middle-income countries. At the individual country level, these patterns applied to a small majority of high-income countries and around two-thirds of middle-income countries. More pronounced was a download–upload divide with download speeds across both fixed and mobile network around three times faster on average than upload speeds; something likely to hamper digital economy development.

Finally, the ability of crowdsourced tests to provide download, upload and latency data allows – despite access being limited to data aggregates – the creation of new broadband service quality indices; valuable given the clear policy signals that such scoring provides. There are many possible ways in which these could have been approached but here we weighted the three elements equally and calculated separate indices for fixed and mobile service quality. The indices are of individual value but plotting them together allowed identification of patterns and outliers that provide some level of policy insight. The indices provide an overview measure and confirmation of the global broadband divide; particularly between high-income and lower-income countries. The same was seen by measuring which countries were ready for particular types of broadband use: none met the high-level threshold but there was a very strong divide between the proportion of high-income vs. lower-income countries meeting the basic threshold. All of this confirms the digital economy / society infrastructure advantage of the former group.

E.2. Aggregated Big Data Benefits and Limitations

On the basis of the analysis undertaken, we can now review this form of aggregated big data in terms of the 'CARTA' data quality issues identified in traditional data by prior literature, looking at both the benefits but also limitations of the dataset exposed here.

Both underlying and aggregated big data is not really more complete than traditional broadband data. Instead, it provides different measures to traditional data: speed and latency rather than speed categories, subscriptions and mobile coverage. Completeness would be improved by combining the two types of data. The big dataset is less complete in terms of country coverage: we derived full data for 112 countries compared to the 192 covered by the ITU. Coverage was particularly incomplete for the lower-income countries: the ITU provides data for all middle-income countries while the Ookla-Cisco dataset covers only 63% of these countries. And ITU provides data for 50 of the 52 low-income countries; full crowdsourced data was only available for eight (15%) of those countries. While coverage may grow over time, this is indicative of a "big data divide" between countries; excluding significant numbers, particularly of the poorest nations from the analysis and also, hence, from the policy and other benefits that big data-based measurement can bring.

Accuracy of underlying big data can only be hypothesised. It may be higher than for traditional broadband data[17]. There is relatively little self-interest in the automatic creation of crowdsourced data; certainly not the issues of commercial confidentiality or desire to inflate speeds that may impact operator reporting. And country-level data is based on multiple – typically many thousands or even millions – of data points, not the reports of a tiny handful of operators. The dataset is methodologically homogeneous: generated by a single company via a single method rather than being gathered from multiple operators, all potentially using their own measurement approaches.

The results above show relevance of this big dataset to be greater than for traditional broadband data. First, in terms of the range of indicators provided. As argued from the literature review, traditional data provides relatively little of relevance to service quality. By allowing access to key service indicators of upload/download speed and latency, crowdsourced data is a significant improvement and, as summarised in the previous sub-section, has allowed analysis of multiple, policy-relevant dimensions of broadband connectivity and the broadband divide. Second, in terms of the nature of the indicators, this dataset provides access to real rather than merely advertised or theoretical speeds; much more relevant for – say – policy makers seeking to guide regulatory or other decisions. Third, and related, in terms of the measures that can be calculated, this big data offers both mean and median measures of average, with the findings above demonstrating that medians are a better measure of typical real experience of broadband.

Raw crowdsourced data is a contemporaneous reflection of the state of broadband in a country. However, that is not the case with the processed dataset – there is a lag in

[17] There is a suggestion (Bauer et al., 2010) that speed test data may be subject to skews due to greater likelihood of testing by those who perceive a problem with their connection. But the existence of such a skew, and its bias e.g. to those with faster- or slower-than-average connections is un-evidenced. We can speculate that awareness and hence usage of speed tests might be greater among more educated, urban populations. However, all of this remains to be researched.

production, it is only available on a yearly basis after production by Cisco, and there is no regular release date despite Ookla releasing its measurement data on a monthly basis[18].

Accessibility of this aggregated dataset is equivalent to that of a sub-set of traditional data in that both are open-access and cost-free. Pre-processing and aggregation of the data by Cisco means users do not require intensive computational power and data science capabilities in order to analyse these data; and thus users can access some of the advantages of big data without encountering some of the barriers typically associated with its application. Analyses such as our own can therefore be readily replicated without direct financial cost and by a broad range of telecommunications/digital policy or other researchers. Although the costs of producing it are lower than traditional data sourced from operators, raw crowdsourced data must be purchased for a fee, just like the data on the paid-for ITU database, except that the costs are well above the US$300 charged by ITU: access to the Ookla dataset costs orders of magnitude more than this, without the right to publish the data. With raw data inaccessible for all but a very few institutions with large budgets and technical capabilities, it is not possible to obtain complete information about the distributions of data measurements within each country (number of observations, maximum and minimum values, etc.). Similarly, basic documentation is available about how the big data were compiled and processed but it is not possible to identify full details of the data preparation and transformation undertaken by Cisco. All of this rather limits the analyses that can be undertaken with the dataset, and accessibilty presents a foundational constraint that analyses of the potential and challenges of big data rarely highlight (Jin et al., 2015; Connelly et al., 2016).

Table 3 summarises the benefits and limitations of using this type of aggregated big data to measure broadband, as found from this analysis.

[18] At the time of writing, Cisco had just released data for 2018 though it was unclear if this was fully updated from the 2017 dataset. The Economist Intelligence Unit releases a dataset based on Ookla data as part of their Inclusive Internet Index but only for 100 countries.

Table 3 Relative benefits and limitations of the Ookla-Cisco dataset in relation to traditional broadband data

Characteristics	Benefits	Limitations
Completeness	-Provides additional measures for 112 countries	-Covers fewer countries and absent for several middle-income and most low-income countries -No ready access to raw data
Accuracy	-Greater accuracy -Methodological homogeneity	-Potential skew
Relevance	-Greater relevance given measures of service quality -Real not theoretical/advertised speeds -Multiple data points via mean and median values	
Timeliness	-Shorter lag time in production	-Made available only on yearly basis -No regular release of dataset
Accessibility	-Aggregated dataset is cost-free, open-access -Use does not require high-level computing or data science capabilities -Ready replicability of analysis	-High cost of raw data -No access to detailed documentation -Methodological limitations of working with aggregated data

F. Conclusions

The fundamental and increasing importance of broadband to national and regional development plans – hence also the growing dangers of broadband divides between those with and those without high-quality services – serves to amplify the need for good broadband data and indicators. Traditional measures, such as those provided through the International Telecommunication Union, have been a valuable basis for understanding broadband. However, there are some limitations of traditional data and so, here, we sought to investigate the implications of using a different data source: hundreds of millions of crowdsourced speed tests. Prior work has shown the potential value of such data, prompting us to undertake a more systematic review.

We found, overall, that – compared to traditional broadband datasets – crowdsourced big data provides additional measures, is more accurate, relevant, timely and accessible. In particular it provides a much better picture of the actual broadband service experienced by users. However, it is also less complete especially for lower-income countries. Because of its high cost, we did not make direct use of the big data that Ookla speed tests produce; instead utilising a freely-available Cisco dataset that pre-processes and aggregates Ookla's big data. While this brought benefits of zero cost and low analytical capacity requirements, it also reduced understanding, control over access, and range of data manipulation. Our work can thus provide only a partial insight into the wider potential of big data but realisation of that potential is currently constrained by access/cost barriers.

This aggregated big dataset confirmed the presence of a global broadband divide between countries at different income levels but it offered an improved method of measuring this divide, based on median rather than mean speeds. The comparative benefits of this form of big data also allowed a deeper insight into the global broadband divide than traditional sources offer, providing an understanding of the asymmetries between fixed and mobile network service, and download vs. upload speeds. It also allowed development of single-score indices to measure broadband service quality and readiness for different levels of data-intensive services; offering a better reflection of actual user needs and experience.

Implications for policy and practice can be considered. At global level, the current limitations of big data suggest that it should be seen as a complement to, rather than substitute for traditional broadband measures. But the additional value it has been shown here to provide, creates a strong argument for its adoption. Likewise at national level, we have shown ways in which crowdsourced data – even in aggregate form – offers policy makers greater understanding of broadband use in their countries; thus providing a basis for better policy decisions than traditional data alone. This includes more realistic measures of speed; better measures of speed that encompass both mean and median values; measures of asymmetries between different network types and between download and upload speeds; and the ability to create single-score indices of broadband service that offer a simple and powerful way to assess broadband readiness and to track improvements over time. This dataset has also highlighted specific issues warranting policy attention: the performance value of relative investments in fixed vs. mobile broadband, and the need for more attention to the relative slowness of upload speeds.

Finally, we recognise some of the limitations of our work which point to directions for future research. We have used only one of the big data sources identified in Table 1, and it will be useful to undertake a comparative analysis of the value offered by each the five shown there. This extension may, for those with funds available, extend to analysis of the raw data where sold by vendors. We focused on particular measures and issues but future research can also broaden this; for example, studying within individual countries patterns over time exposed by big data; using alternative measures and tests of the divides; and trying out different ways to calculate broadband indices.

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Appendix A. Cisco-Ookla Data

Table shows speeds for fixed and mobile networks (Mbps); and latencies (ms). Fixed networks are identified with the prefix "fix" and mobile networks with "mob"; download speeds are contracted as "down" and upload speeds as "up"; means are given the suffix "avg", and medians "med"; latencies are show as "lat".

ITU Country Name	ISO	Income	fixdownavg	fixdownmed	fixupavg	fixupmed	fixavglat	fixmedlat	mobdownavg	mobdownmed	mobupavg	mobupmed	mobavglat	mobmedlat
Afghanistan	AFG	Low	4	2.5	3.4	2	59	17	3.3	2.1	1.1	0.8	96	55
Albania	ALB	Mid	10.1	7	6.6	1.8	42	26	11.1	8.4	5.7	2.6	40	27
United Arab Emirates	ARE	High	23.7	17	9.7	5.4	23	7	25.2	22.6	12.4	5.3	45	29
Argentina	ARG	Mid	7	5	1.8	0.9	53	30	9	6.9	5.4	2.6	58	43
Armenia	ARM	Mid	13	6.1	9.8	3.1	31	19	9.6	5.5	5.4	1.4	34	27
Australia	AUS	High	19.2	11	7.5	1	41	21	28	21	11.7	7.4	36	27
Austria	AUT	High	28.9	19.1	8.2	5.9	26	15	27.3	22.4	12.1	7.7	31	26
Azerbaijan	AZE	Mid	7.9	3.8	7.7	0.9	44	32	10.3	6.9	4.4	2	50	36
Belgium	BEL	High	45.1	33.8	10	7	25	14	30	22.9	13	9.7	30	25
Bangladesh	BGD	Low	10.8	3.8	9.2	3	39	9	4.3	3.2	1.5	1.2	70	43
Bulgaria	BGR	Mid	37.7	31.8	27.5	19.2	17	9	25	20.3	12.6	6.5	33	28
Bahrain	BHR	High	14.7	9.8	5.5	2.1	29	18	9.3	5.9	8.2	4.4	39	24
Bosnia and Herzegovina	BIH	Mid	16.5	9.5	3.8	1.4	34	20	9.1	7.6	2.2	1.9	45	37
Belarus	BLR	Mid	17.9	9.7	15	5.3	27	15	13.1	9.9	10.3	4.4	34	28
Bolivia (Plurinational State of)	BOL	Mid	3.9	2.9	1.3	0.8	46	18	5.9	4.6	5.1	1.6	59	39
Brazil	BRA	Mid	13.2	8.1	5.1	1.6	42	20	10.5	6.8	5.4	2	79	59
Canada	CAN	High	36.6	26.6	15.5	9.8	32	15	39.2	28.2	12.4	8.5	40	31
Switzerland	CHE	High	71.8	41.6	37.1	13.5	21	13	31.6	20.6	12.8	9.1	32	27
Chile	CHL	Mid	26.4	18	9.1	6	35	18	15.7	9.3	9	4.5	46	32
China	CHN	Mid	47.5	40.7	17	6.3	17	9	37.9	32.2	18.3	11.9	44	32
Colombia	COL	Mid	7.4	5.2	3.2	1.1	50	32	8.2	5.8	5.7	2	80	54
Costa Rica	CRI	Mid	6.8	5.6	3.3	1.7	41	13	3.4	2.9	1.9	1.2	73	41
Cyprus	CYP	High	14.2	8.9	3.4	1	35	24	10.8	8.5	4.9	2.3	52	34
Czech Republic	CZE	High	28.1	18.9	17.3	8.5	22	15	23.2	19.1	12.7	11.3	32	26

ITU Country Name	ISO	Income	fixdownavg	fixdownmed	fixupavg	fixupmed	fixavglat	fixmedlat	mobdownavg	mobdownmed	mobupavg	mobupmed	mobavglat	mobmedlat
Germany	DEU	High	40.7	29.9	9.6	5.9	31	21	22.9	15.4	8.9	4.7	56	43
Denmark	DNK	High	63	46.6	49.5	27.3	17	10	37.9	27.7	16.4	12.9	28	22
Dominican Rep.	DOM	Mid	16.1	9.2	3.9	2	45	16	10.1	6.4	4.5	1.9	55	38
Algeria	DZA	Mid	2.7	1.9	0.8	0.5	72	45	4.1	2.5	1.8	1	70	50
Ecuador	ECU	Mid	6.7	4.1	5	1.4	41	20	8.4	5.2	7.9	1.9	54	43
Egypt	EGY	Mid	4	2.3	1.1	0.6	58	33	5.9	5.2	3	2.1	52	36
Spain	ESP	High	50.3	30.2	43	10	36	22	31.6	22.3	14	6.8	53	43
Estonia	EST	High	28.6	18.8	20	9.4	23	13	23.3	14.9	9.7	5.1	29	21
Finland	FIN	High	37.4	23.8	17.9	9.9	28	20	27.2	21.6	12.3	8.2	31	26
France	FRA	High	33.5	10.9	18.8	1	37	24	27.5	18.9	9.1	5.3	47	36
United Kingdom	GBR	High	33.7	25.6	9.7	6.2	31	18	25.2	18.2	10.6	7.2	43	38
Georgia	GEO	Mid	13	8.7	12.5	7.7	40	14	12.4	8.9	8.3	4.9	49	30
Ghana	GHA	Mid	7.5	4.2	6.6	2.5	62	24	8.2	5.6	4.4	1.8	68	38
Greece	GRC	High	11.3	9.2	1.5	0.8	43	26	15.9	13.7	6.4	3.5	41	29
Guatemala	GTM	Mid	5	4.1	1.9	1	58	22	7.6	6.4	5.2	3	47	35
Hong Kong, China	HKG	High	117.3	66.8	117.1	49.4	20	5	25	16.3	12.1	6.4	36	27
Honduras	HND	Mid	4.3	3	3.1	1	54	20	5.7	5	3.1	1.3	77	59
Croatia	HRV	High	16.6	10.8	5.5	2	31	20	19.7	18.2	9	4.7	37	28
Hungary	HUN	High	49.2	30.5	20.2	9.3	23	14	39.1	32.1	15.7	11	34	22
Indonesia	IDN	Mid	9.4	7.4	6.3	1.7	33	15	8	5.4	6	3.8	52	41
India	IND	Mid	9.5	5.9	8.9	3.4	39	19	7.1	4.4	3.2	2.2	71	50
Ireland	IRL	High	32.3	21.9	12.1	8.7	36	19	19.2	11.5	8.5	4	39	33
Iran (Islamic Republic of)	IRN	Mid	6.3	4.8	3.2	0.8	42	31	10.3	7.9	5.5	3.2	56	36
Iraq	IRQ	Mid	6.9	4.6	6.1	3.1	50	18	4.9	2	3.1	1.2	92	47
Israel	ISR	High	33.8	28.7	4.3	2.8	24	15	19.6	13	9.7	4	35	27
Italy	ITA	High	16.4	10.7	6.6	1	43	29	20.3	14.3	8.6	4.5	49	43
Jamaica	JAM	Mid	10.6	6.8	3.3	1	56	27	10.5	6.2	4.1	2.1	52	34
Jordan	JOR	Mid	12.4	8.2	8.2	2	43	20	11.1	8.2	9.8	4.7	43	23

ITU Country Name	ISO	Income	fixdownavg	fixdownmed	fixupavg	fixupmed	fixavglat	fixmedlat	mobdownavg	mobdownmed	mobupavg	mobupmed	mobavglat	mobmedlat
Japan	JPN	High	77.9	41.6	73.1	40.7	32	21	30	16.2	12.6	8.5	59	50
Kazakhstan	KAZ	Mid	19.3	8.2	18.4	3.9	40	28	12.7	8.1	9.1	4	49	38
Kenya	KEN	Low	9	5.4	6	2.6	43	15	13.5	9.6	7.4	3.8	49	33
Kyrgyzstan	KGZ	Mid	12.2	6	11.5	3.5	36	21	10	6.4	5.2	2.1	47	35
Cambodia	KHM	Low	9.2	6.1	8.9	5	19	7	6.1	3.8	6	3.2	42	29
Korea (Rep. of)	KOR	High	88.9	72	85.2	67.2	14	7	38.7	26.1	14.4	11.4	53	31
Kuwait	KWT	High	10.4	6.5	9.2	3	26	8	12.4	8	12	6.3	43	25
Lebanon	LBN	Mid	2.7	1.8	1.8	0.7	64	42	4.2	3.8	3.2	1.7	56	39
Sri Lanka	LKA	Mid	15.9	10.2	6	1.4	45	25	7.1	5.4	3.3	1.9	53	36
Lithuania	LTU	High	55.1	35.6	52.7	27.3	19	10	32.6	23.8	14.3	9.3	31	24
Luxembourg	LUX	High	50.7	30.2	27.7	13.6	24	16	33.4	27	13.6	10.1	34	28
Latvia	LVA	High	45.7	29.7	45.6	24.8	17	8	26	20.1	12.2	7.7	28	18
Macao, China	MAC	High	65	47.5	64.1	46.8	10	4	25.4	13.8	12.3	5.3	32	21
Morocco	MAR	Mid	10.3	4.1	1.9	0.4	79	46	11.7	8.9	6.3	3.4	47	33
Moldova	MDA	Mid	39	25.8	34.3	17.7	24	9	16.5	9.6	7.4	2	35	28
Maldives	MDV	Mid	10.5	4.8	8.3	2.9	46	8	13.7	11	9.8	4.4	48	29
Mexico	MEX	Mid	14.6	9.8	6.9	2	46	26	13.4	10.4	9.3	4.7	64	49
The Former Yugoslav Rep. of Macedonia	MKD	Mid	13.8	9.2	9.2	1	34	21	16.3	11	9.2	2.5	40	30
Malta	MLT	High	36.9	29.7	5.2	3.1	22	11	38.1	32.2	10.3	4.6	22	15
Montenegro	MNE	Mid	14.9	12.6	2.3	1.7	31	22	15.7	11.9	7.5	3	36	28
Mongolia	MNG	Mid	14.2	3.9	14.1	3.1	38	11	12.1	7.4	8.7	3.4	44	32
Mozambique	MOZ	Low	3.4	2.6	2.9	1.7	72	29	8.4	6.7	2.3	2.2	60	36
Malaysia	MYS	Mid	15	8.5	9.1	6	44	20	11	7.1	6	2.9	51	37
Nigeria	NGA	Mid	5.7	3.7	5.5	3	84	37	6.7	4	3.1	1.8	118	67
Nicaragua	NIC	Mid	4.7	3.3	2.7	1.1	53	19	6	4.6	4.5	1.3	51	38
Netherlands	NLD	High	56.4	40.6	26.5	15.4	22	12	46.5	36.5	16.7	12.3	32	27
Norway	NOR	High	45	30.3	34.3	17	26	10	54.8	42.5	17.6	13.2	37	32
New Zealand	NZL	High	39.9	26.4	24.5	9.9	27	16	32	21	13.3	7.6	43	36

ITU Country Name	ISO	Income	fixdownavg	fixdownmed	fixupavg	fixupmed	fixavglat	fixmedlat	mobdownavg	mobdownmed	mobupavg	mobupmed	mobavglat	mobmedlat
Oman	OMN	High	9.8	5.4	5.8	0.9	69	23	15.2	12.1	9.8	3.8	50	37
Pakistan	PAK	Mid	4.9	3.2	3.8	1	59	35	7	5.6	4.2	2.4	78	48
Panama	PAN	Mid	13.3	8.2	4.5	3.4	42	16	13.4	10.3	7.7	4.5	67	39
Peru	PER	Mid	8.5	5.9	2.3	0.7	64	35	11.5	9	9	5.2	62	38
Philippines	PHL	Mid	9	4.6	7.7	0.8	58	30	7.7	5	5	2.4	56	37
Poland	POL	High	30.2	18.7	11.8	5.9	28	19	17.9	12.3	8.6	4.9	39	34
Portugal	PRT	High	42.2	28	20.3	8.5	23	13	22.4	12.1	10.2	4.7	36	29
Paraguay	PRY	Mid	5.2	3.9	3.7	2	40	15	7.6	5.9	4.8	3	82	43
Qatar	QAT	High	18.7	11	13.1	5.5	23	5	26.1	17.3	12.8	8.8	42	21
Romania	ROU	Mid	94.7	54.8	70.2	42	19	9	35.9	16	14.2	5.5	38	28
Russian Federation	RUS	Mid	33.8	21.9	30.9	21.9	23	8	12	7.4	6	3	57	45
Saudi Arabia	SAU	High	12.2	7.5	6.4	1.1	47	31	8.5	4.7	6.8	3.4	58	39
Singapore	SGP	High	142.6	66.4	139.8	55.4	14	4	63.6	46.2	33.5	20.5	30	21
El Salvador	SLV	Mid	4	3.3	1.5	0.7	66	27	4.8	4.4	2	1.4	64	49
Serbia	SRB	Mid	19.4	11.3	2.8	1.9	25	14	19.3	15.5	7.4	3.9	30	25
Slovakia	SVK	High	28.7	15.7	12	3.9	27	18	24.7	20.3	9.9	7.7	34	30
Slovenia	SVN	High	25.2	13.6	9.9	3.3	27	13	20.9	17.5	8.1	5.1	28	21
Sweden	SWE	High	60.3	44.4	42.9	11.6	24	10	33.8	22.3	11.8	6.5	50	32
Thailand	THA	Mid	34.7	30.3	13.9	10.8	22	13	30.3	30.2	15	14.1	29	23
Trinidad and Tobago	TTO	High	21.7	18.4	6.5	3	27	12	14	9	5.2	3.1	37	22
Tunisia	TUN	Mid	5.2	3.5	2.1	0.8	51	31	8.4	6.5	3.9	2.2	37	28
Turkey	TUR	Mid	11.9	7	3.4	1.1	34	19	15.7	12.1	7.6	3.9	41	33
Tanzania	TZA	Low	5.4	3.4	5.3	3	49	22	5.2	3.4	3.4	1.9	57	40
Uganda	UGA	Low	3.3	2.1	3	2	48	22	5.2	3.8	1.9	1.6	74	46
Ukraine	UKR	Mid	28.1	15.9	28.1	14.4	28	16	9.1	6.4	5	2.5	52	45
Uruguay	URY	Mid	20.1	16	5	4.2	30	12	13.7	8.7	7.1	3	49	38
United States	USA	High	46.2	33.3	16.7	6.2	34	19	33.9	17.2	15.8	6.3	69	29
Uzbekistan	UZB	Mid	3.6	2.2	3.2	1	50	27	6.6	5.4	3	1.8	58	39
Venezuela	VEN	Mid	2.7	1.8	0.9	0.6	93	62	3.5	2.8	1.4	1	100	75

ITU Country Name	ISO	Income	fixdownavg	fixdownmed	fixupavg	fixupmed	fixavglat	fixmedlat	mobdownavg	mobdownmed	mobupavg	mobupmed	mobavglat	mobmedlat
Viet Nam	VNM	Mid	21.6	17.3	20.6	17.2	13	4	9.5	6.7	4.6	2.2	42	35
South Africa	ZAF	Mid	7.7	4.6	4.6	0.9	44	25	23.2	17.8	9.6	5.5	37	26
Zimbabwe	ZWE	Low	4.9	2.5	4.1	1.5	42	23	6.7	5.4	2.7	1.1	68	46

Appendix B. Broadband Indices Scores

ITU Country Name	ISO	Region WB	Income Level	ifix	imob
Afghanistan	AFG	South Asia	Low	0.269928558	0.111865259
Albania	ALB	Europe & Central Asia	Middle	0.238573938	0.345388979
United Arab Emirates	ARE	Middle East & North Africa	High	0.413216793	0.487052137
Argentina	ARG	Latin America & Caribbean	Middle	0.201597738	0.245187873
Armenia	ARM	Europe & Central Asia	Middle	0.281017344	0.303214124
Australia	AUS	East Asia & Pacific	High	0.282310906	0.521629878
Austria	AUT	Europe & Central Asia	High	0.379706301	0.542819645
Azerbaijan	AZE	Europe & Central Asia	Middle	0.184405479	0.273924478
Belgium	BEL	Europe & Central Asia	High	0.460743019	0.585986887
Bangladesh	BGD	South Asia	Low	0.327068429	0.193595741
Bulgaria	BGR	Europe & Central Asia	Middle	0.540860219	0.495566861
Bahrain	BHR	Middle East & North Africa	High	0.299343302	0.373658804
Bosnia and Herzegovina	BIH	Europe & Central Asia	Middle	0.282931534	0.27195591
Belarus	BLR	Europe & Central Asia	Middle	0.332077911	0.381602494
Bolivia (Plurinational State of)	BOL	Latin America & Caribbean	Middle	0.260092743	0.233144222
Brazil	BRA	Latin America & Caribbean	Middle	0.277281864	0.145392552
Canada	CAN	North America	High	0.434779915	0.572318819
Switzerland	CHE	Europe & Central Asia	High	0.535962313	0.547378092
Chile	CHL	Latin America & Caribbean	Middle	0.357740752	0.356547432
China	CHN	East Asia & Pacific	Middle	0.51874917	0.654458787
Colombia	COL	Latin America & Caribbean	Middle	0.192051157	0.165628852
Costa Rica	CRI	Latin America & Caribbean	Middle	0.306139906	0.202444409
Cyprus	CYP	Europe & Central Asia	High	0.255098017	0.302178096
Czech Republic	CZE	Europe & Central Asia	High	0.391730685	0.578846473
Germany	DEU	Europe & Central Asia	High	0.396505594	0.344823432
Denmark	DNK	Europe & Central Asia	High	0.645807658	0.692998165
Dominican Rep.	DOM	Latin America & Caribbean	Middle	0.30748955	0.25735058
Algeria	DZA	Middle East & North Africa	Middle	0.098674985	0.146043723
Ecuador	ECU	Latin America & Caribbean	Middle	0.257290508	0.220523029
Egypt	EGY	Middle East & North Africa	Middle	0.17003884	0.262796013
Spain	ESP	Europe & Central Asia	High	0.412642051	0.432392626
Estonia	EST	Europe & Central Asia	High	0.407241122	0.470043105
Finland	FIN	Europe & Central Asia	High	0.393247938	0.545246699
France	FRA	Europe & Central Asia	High	0.264594693	0.420259779
United Kingdom	GBR	Europe & Central Asia	High	0.394826125	0.436018533
Georgia	GEO	Europe & Central Asia	Middle	0.345052747	0.371410142
Ghana	GHA	Sub-Saharan Africa	Middle	0.240265858	0.249625351
Greece	GRC	Europe & Central Asia	High	0.244030262	0.389476129

ITU Country Name	ISO	Region WB	Income Level	ifix	imob
Guatemala	GTM	Latin America & Caribbean	Middle	0.243800247	0.292629768
Hong Kong, China	HKG	East Asia & Pacific	High	0.88073916	0.469264457
Honduras	HND	Latin America & Caribbean	Middle	0.250071328	0.11997356
Croatia	HRV	Europe & Central Asia	High	0.292098385	0.449272905
Hungary	HUN	Europe & Central Asia	High	0.45655055	0.694031769
Indonesia	IDN	East Asia & Pacific	Middle	0.303192662	0.265291336
India	IND	South Asia	Middle	0.281564683	0.1806771
Ireland	IRL	Europe & Central Asia	High	0.383985198	0.359122892
Iran (Islamic Republic of)	IRN	Middle East & North Africa	Middle	0.194401942	0.301770525
Iraq	IRQ	Middle East & North Africa	Middle	0.279641964	0.162323745
Israel	ISR	Middle East & North Africa	High	0.409821285	0.403768442
Italy	ITA	Europe & Central Asia	High	0.234909393	0.333143712
Jamaica	JAM	Latin America & Caribbean	Middle	0.227885128	0.281448602
Jordan	JOR	Middle East & North Africa	Middle	0.279752706	0.401635901
Japan	JPN	East Asia & Pacific	High	0.625713844	0.376265526
Kazakhstan	KAZ	Europe & Central Asia	Middle	0.243256732	0.305704088
Kenya	KEN	Sub-Saharan Africa	Low	0.298187004	0.341409988
Kyrgyzstan	KGZ	Europe & Central Asia	Middle	0.271044266	0.277401342
Cambodia	KHM	East Asia & Pacific	Low	0.3594639	0.309739353
Korea (Rep. of)	KOR	East Asia & Pacific	High	0.982758621	0.605551089
Kuwait	KWT	Middle East & North Africa	High	0.345636068	0.416089252
Lebanon	LBN	Middle East & North Africa	Middle	0.116439535	0.228803087
Sri Lanka	LKA	South Asia	Middle	0.257519738	0.260920213
Lithuania	LTU	Europe & Central Asia	High	0.593575939	0.591561584
Luxembourg	LUX	Europe & Central Asia	High	0.465088881	0.60700847
Latvia	LVA	Europe & Central Asia	High	0.564579947	0.56991869
Macao, China	MAC	East Asia & Pacific	High	0.78186931	0.465131574
Morocco	MAR	Middle East & North Africa	Middle	0.102875201	0.329362764
Moldova	MDA	Europe & Central Asia	Middle	0.50488516	0.338730913
Maldives	MDV	South Asia	Middle	0.337064892	0.384342564
Mexico	MEX	Latin America & Caribbean	Middle	0.252867288	0.273782708
The Former Yugoslav Rep. of Macedonia	MKD	Europe & Central Asia	Middle	0.273763898	0.346638109
Malta	MLT	Middle East & North Africa	High	0.439055135	0.625383773
Montenegro	MNE	Europe & Central Asia	Middle	0.287654135	0.372996787
Mongolia	MNG	East Asia & Pacific	Middle	0.316548012	0.323606103
Mozambique	MOZ	Sub-Saharan Africa	Low	0.199940869	0.275800277
Malaysia	MYS	East Asia & Pacific	Middle	0.301137287	0.285105644
Nigeria	NGA	Sub-Saharan Africa	Middle	0.165674055	0.076447874

ITU Country Name	ISO	Region WB	Income Level	ifix	imob
Nicaragua	NIC	Latin America & Caribbean	Middle	0.257741958	0.233623636
Netherlands	NLD	Europe & Central Asia	High	0.546442139	0.721433111
Norway	NOR	Europe & Central Asia	High	0.517012541	0.754132628
New Zealand	NZL	East Asia & Pacific	High	0.428582123	0.475013973
Oman	OMN	Middle East & North Africa	High	0.243726958	0.338041462
Pakistan	PAK	South Asia	Middle	0.164814099	0.204222079
Panama	PAN	Latin America & Caribbean	Middle	0.30972724	0.325200021
Peru	PER	Latin America & Caribbean	Middle	0.176137606	0.332795987
Philippines	PHL	East Asia & Pacific	Middle	0.199199401	0.260808304
Poland	POL	Europe & Central Asia	High	0.35481846	0.374828945
Portugal	PRT	Europe & Central Asia	High	0.446434815	0.397714332
Paraguay	PRY	Latin America & Caribbean	Middle	0.288070484	0.244414585
Qatar	QAT	Middle East & North Africa	High	0.396720019	0.550748406
Romania	ROU	Europe & Central Asia	Middle	0.76384445	0.446218032
Russian Federation	RUS	Europe & Central Asia	Middle	0.513071852	0.244615691
Saudi Arabia	SAU	Middle East & North Africa	High	0.208719461	0.264355223
Singapore	SGP	East Asia & Pacific	High	0.914527071	0.966666667
El Salvador	SLV	Latin America & Caribbean	Middle	0.209768938	0.172696276
Serbia	SRB	Europe & Central Asia	Middle	0.328456311	0.432041201
Slovakia	SVK	Europe & Central Asia	High	0.336340532	0.504760319
Slovenia	SVN	Europe & Central Asia	High	0.352110643	0.489650948
Sweden	SWE	Europe & Central Asia	High	0.557018001	0.488427595
Thailand	THA	East Asia & Pacific	Middle	0.468833038	0.726600873
Trinidad and Tobago	TTO	Latin America & Caribbean	High	0.379152786	0.386151881
Tunisia	TUN	Middle East & North Africa	Middle	0.188229102	0.318736426
Turkey	TUR	Europe & Central Asia	Middle	0.275310809	0.361955731
Tanzania	TZA	Sub-Saharan Africa	Low	0.25045645	0.223615035
Uganda	UGA	Sub-Saharan Africa	Low	0.239293591	0.188222151
Ukraine	UKR	Europe & Central Asia	Middle	0.401179662	0.228613976
Uruguay	URY	Latin America & Caribbean	Middle	0.373744798	0.293308501
United States	USA	North America	High	0.425641202	0.463248629
Uzbekistan	UZB	Europe & Central Asia	Middle	0.206042772	0.242561499
Venezuela	VEN	Latin America & Caribbean	Middle	0.000998004	0.009417277
Viet Nam	VNM	East Asia & Pacific	Middle	0.490764909	0.281355833
South Africa	ZAF	Sub-Saharan Africa	Middle	0.228434035	0.470903803
Zimbabwe	ZWE	Sub-Saharan Africa	Low	0.23295079	0.191828279